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DESCRIPTION

FUEL BATTERY SYSTEM AND VEHICLE USING THE SAME

TECHNICAL FIELD

The present invention relates to a general energy generating system, and is particularly effective for a system having an internal combustion engine serving as both of a reformer and a power generator. The present invention relates to a general energy generating system in which a function as a reformer is added to an internal combustion engine to actively make use of explosion energy which can not used by a conventional reformer. This system improves the efficiency of fuel reforming and the efficiency of the total system in the fuel battery or fuel cell system by improving heat balance. The present invention is effective when it is applied to an object which outputs a mechanical power and requires a small sized high efficiency system, and particularly effective when it is applied to a vehicle.

BACKGROUND ART

As consciousness about energy and environment problems is being raised, high efficiency and low emission vehicles are required. The fuel battery has attracted attention as a high efficiency prime mover because the fuel battery extracts energy from fuel not through combustion

and exhausts only water. However, since the fuel battery uses hydrogen as the fuel, it is difficult to mount the fuel battery on a vehicle which requires small size and light weight. Therefore, a method that a chemical composition containing hydrogen such as methanol is mounted on a vehicle and is reformed to hydrogen in the vehicle is proposed. The method of reforming the fuel used is a method accelerating reaction rate using a catalyst without supplying heat from the external. For example, a system in which heat necessary for steam reforming is supplied using reaction heat of oxidation reaction of methanol is disclosed in Japanese Patent Application Laid-Open No.9-315801.

DISCLOSURE OF INVENTION

However, since the conventional fuel reformer uses a catalyst to cause the reaction at a relatively low temperature, the thermal energy accompanied by explosion can not be used in a form other than self heating.

In order to solve the above-mentioned problem, in the present invention, by using an internal combustion engine also as a reformer to effectively use generated heat accompanied by reforming reaction, intake gas is heated using the heat energy of the system to improve the reformation efficiency. Thereby, a high efficiency fuel

battery system can be provided. Further, the fuel battery system also has an advantage in that the reforming efficiency is small in variation with time because any special catalyst is not used.

The present invention is characterized by an energy generating system comprising one or more front stage reaction means which receives a raw material to generate a reaction product; and a rear stage reaction means which receives the reaction product to generate energy, wherein the front stage reaction means produces the reaction product by receiving mechanical power from the outside, or outputs mechanical power generated by chemical reaction in the front stage reaction means to the outside.

The present invention is preferably characterized by that at least one of the front stage reaction means receives the raw material and said mechanical power, and produces a reaction product having a chemical energy higher than a chemical energy of the raw material.

The present invention is preferably characterized by that at least one of the front stage reaction means produces a reaction product different from the raw material in combustive property.

The present invention is preferably characterized by that the front stage reaction means comprises a reaction composition control means for control the reaction product

or composition rates of the reaction product, wherein a root pipe connected to a reaction product output port of the front stage reaction means is branched into at least two conveying pipes, at least one of the conveying pipes being connected to the rear stage reaction means, the energy generating system comprising a use pipe selecting means, the use pipe selecting means switching the conveying pipe to be used using information from the reaction composition control means.

The present invention is preferably characterized by that the front stage reaction means comprises an energy converting means for converting electric energy to mechanical power or mechanical power to electric energy.

The present invention is preferably characterized by that the front stage reaction means and the rear reaction means are connected to each other through a heat transfer means.

The present invention is preferably characterized by that the front stage reaction means is a heat engine, and the rear stage reaction means is a fuel battery.

The present invention is preferably characterized by that the heat engine performs the front reaction in a steam atmosphere using water supplied from a water supply means.

The present invention is preferably characterized by that the heat engine is an internal combustion engine, the

internal combustion engine comprising a fuel injection valve, a reaction composition control means controlling an amount of fuel injected from the fuel injection valve.

The present invention is preferably characterized by that the heat engine is an internal combustion engine, the internal combustion engine comprising a variable drive valve, a reaction composition control means controlling a compression ratio of the internal combustion engine by changing opening-and-closing timings of the variable drive valve.

The present invention is preferably characterized by that the heat engine has a time period to generate mechanical power, and the heat engine supplies compressed air to the fuel battery using the mechanical power.

The present invention is preferably characterized by that the heat engine has a time period to perform either of or both of reforming reaction for generating fuel to be supplied to the fuel battery and mechanical power generating reaction, and the energy generating system comprises a low temperature heat transfer means for heating a raw material to be injected into the heat engine using generated heat accompanied by electric generation of the fuel battery, or a high temperature heat transfer means for heating the raw material to be injected into the heat engine using exhaust heat of the heat engine itself.

The present invention is preferably characterized by that the energy generating system comprises a heating means for heating a raw material to be injected into the heat engine; and a fuel selecting means between the heat engine and the fuel battery, wherein the fuel selecting means selecting reaction fuel to be supplied to the fuel battery and heating fuel to be supplied to the heating means, the heating means using the heating fuel as fuel of the heating means.

The present invention is preferably characterized by that the energy generating system comprises a heating means for heating a raw material to be injected into the heat engine; and a fuel collecting means in a reaction product output port of the fuel battery, wherein the heating means uses un-reacted fuel in said fuel battery collected by the fuel collecting means as fuel of the heating means.

The present invention is preferably characterized by that the internal combustion engine comprises an intake pipe for transporting a raw material, and the following relation is satisfied, that is, $L1 < L2 < L3$ where L1 is a distance of the intake pipe of the internal combustion engine along the heating means, L2 is a distance of the intake pipe of the internal combustion engine along the high temperature heat transfer means, and L3 is a distance of the intake pipe of the internal combustion engine along

the low temperature heat transfer means.

The present invention is preferably characterized by that the heating means controls an amount of the supplied heat in order to heat the injected raw material to a target temperature indicated by a temperature control means by changing a supply ratio of un-reacted fuel components from the fuel battery and exhaust substances from the fuel selecting means.

The present invention is preferably characterized by that the heat engine is an internal combustion engine, the energy generating system transferring heat generated by the fuel battery to the internal combustion engine, or heat generated by the internal combustion engine to the fuel battery, the heating means heating the raw material to be injected to the internal combustion engine, the energy generating system comprising a temperature control means for the internal combustion engine and the fuel battery, the temperature control means controlling amounts of heat of the heat transfer means and the heating means and an amount of supplied fuel so that temperature in a reaction chamber of the internal combustion engine just before ignition may become a temperature above a self-ignition temperature of the raw material under an atmosphere in the reaction chamber, the temperature control means controlling amounts of heat of the heat transfer means and the heating

means and an amount of supplied fuel so that temperature of fuel to be supplied to the fuel battery may become an operating temperature of the fuel battery.

The present invention is preferably characterized by that the temperature control means comprises an internal combustion engine control means for controlling the internal combustion engine, the internal combustion engine control means receiving intake raw material temperature information transmitted from the temperature control means, the internal combustion engine control means controlling an amount of produced fuel to be supplied to the fuel battery using any items of information on an equivalent ratio, a compression ratio, a compression history, a cooling water temperature, a lubricant oil temperature, a lubricant oil pressure, an intake gas flow rate and a compression speed.

The present invention is preferably characterized by a vehicle mounting the energy generating system, wherein the vehicle comprises a motor for converting electric power obtained from the fuel battery to mechanical power, and an output shaft of the motor and a mechanical power output shaft of the heat engine are connected to a wheel shaft through a mechanical transmission element.

The present invention is preferably characterized by a vehicle mounting the energy generating system, wherein the vehicle comprises an electricity storing means for

storing direct current electric power obtained from the fuel battery, a mechanical power output shaft of the heat engine being connected to a electric generator, alternating current electric power obtained from the electric generator being converted to direct current electric power by an alternating current electric power converting means to be stored in the electricity storing means, the vehicle comprising a motor for driving the vehicle using the electricity stored in the electricity storing means, an output shaft of the motor being connected to a wheel shaft through a mechanical transmission element.

The present invention is preferably characterized by that the vehicle comprises an energy control means which receives a command signal of a driver and vehicle information and an internal state of the fuel battery as inputs, and controls a reaction composition control means and the electric generator and the motor based on the inputs.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a block diagram showing the construction of an embodiment of a vehicle mounting a fuel battery in accordance with the present invention.

FIG. 2 is a block diagram showing the construction of an embodiment of a temperature control means of a reformer

engine.

FIG. 3 is a block diagram showing the construction of an embodiment of a vehicle mounting a fuel battery in accordance with the present invention.

FIG. 4 is a view showing an embodiment of an energy generating system using an internal combustion engine in accordance with the present invention.

FIG. 5 is a block diagram showing the construction of an energy generating system in accordance with the present invention.

FIG. 6 is a view showing an embodiment of an energy generating system using an internal combustion engine in accordance with the present invention.

FIG. 7 is a block diagram showing the construction of an energy generating system in accordance with the present invention.

FIG. 8 is a block diagram showing the construction of an energy generating system in accordance with the present invention.

FIG. 9 is a block diagram showing the construction of an energy generating system in accordance with the present invention.

FIG. 10 is a block diagram showing the construction of an energy generating system in accordance with the present invention.

FIG. 11 is a block diagram showing the construction of an energy generating system in accordance with the present invention.

FIG. 12 is a block diagram showing the construction of an energy generating system in accordance with the present invention.

FIG. 13 is a block diagram showing the construction of an embodiment of a vehicle mounting a fuel battery in accordance with the present invention.

FIG. 14 is a view explaining the construction of a reformer engine.

FIG. 15 is a view showing an example of a water collecting means.

FIG. 16 is a block diagram showing the construction of an example of an energy control means.

FIG. 17 is a block diagram showing the construction of an example of a rotation speed correcting means.

FIG. 18 is a block diagram showing the construction of an embodiment of a vehicle mounting a fuel battery in accordance with the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

Embodiments of the present invention will be described below.

FIG. 1 is an embodiment of a vehicle mounting an energy generating system in accordance with the present

invention. The reference character 91 is a drive shaft of the vehicle. The reference character 92 is a reformer engine using an internal combustion engine which characterizes the present invention. The reference character 93 is a fuel battery which generates direct current electric power by supplying fuel such as hydrogen obtained by the reformer engine 92 to a fuel electrode and an oxidizing agent such as air to an air electrode. That is, in the present system, the front stage reactor is the reformer engine of a reformer also serving as an internal combustion engine, and the rear stage reactor is the fuel battery of an electric energy generator. Therein, the internal combustion engine means an engine using a combustion gas as the operating fluid the category of which a reciprocal engine, a rotary engine, a gas turbine, a jet engine or the like is included in. In the case of FIG. 1, the internal combustion engine is assumed to be a reciprocal engine as an example. Further, the reformer engine in the present specification means a machine generating both of a fuel reformed reforming reaction and mechanical power, or a machine performing reforming process using mechanical power.

The reformer engine 92 is composed of a plurality of cylinders, and each of the cylinders has a reaction chamber for reforming a raw material. Further, the reformer engine

92 has a means for compressing and delivering air to be supplied to the air electrode of the fuel battery. As an embodiment, in a case where the raw material is methane and the reaction product is hydrogen, the fuel reforming reaction is further accelerated as the temperature is higher. In the present invention, temperature of the atmosphere of the reaction chamber of the reformer engine 92 is increased up to the self-ignition temperature of the raw material, which has been impossible in the conventional reformer. Thereby, the present invention is characterized by that the amount of produced hydrogen can be increased and at the same time mechanical power can be also generated. Further, since any special catalyst is not used, the energy generating system of the present invention is unrelated to deterioration of the reforming efficiency with time and the incapable time period at cold starting.

As the reforming reactions performed in the reaction chamber of the reformer engine 92, at least one of the cylinder is normally selected for an exothermic reaction. The raw material is heated by the exothermic reaction. The detail is to be described later. Since the reformer engine 92 is composed of the plurality of cylinders, the operation can be performed if at least one of the cylinders generates an output enough to cover the compression stroke of the other remaining cylinders. Furthermore, it is assumed that

the reformer engine 92 in this configuration uses mechanical power generated by itself as a power source to deliverer the reformed fuel to the fuel battery 93.

The reference character 94 is a fuel selecting means which classify the exhausted substances from the reformer engine 92 into a component to be supplied to the fuel battery 93 and the other components. Hereinafter, the reaction product to be supplied to the fuel battery is referred to as a fuel, and the components other than the fuel is referred to as an un-reacted raw material.

The reference character 95 is a generator also serving as a motor which is mechanically connected to the reformer engine 92. The generator also serving as a motor 95 works as a generator when mechanical power is generated from the reformer engine 92, and works as a motor when mechanical power is required from the reformer engine 92.

The reference character 96 is an energy converting means which converts mechanical power from the reformer engine 92 to electric power or supplies mechanical power to the reformer engine 92. A motor capable of generating electricity and outputting mechanical power is generally used for the energy converting means.

The reference character 97 is a motor driving means which drives a motor using electric energy from the fuel battery 93 and the energy converting means 96, and the

motor driving means comprises a secondary battery, a converter and an inverter. The reference character 98 is the motor, and an alternating current motor such as an induction motor, a synchronous motor, a reluctance motor or the like is generally used for the motor because of toughness and high efficiency.

In order to improve the reforming efficiency of the reformer engine 92, the temperature in the reaction chamber is preferably increased furthermore. The present invention is characterized by that the inlet temperature of the reformer engine 92 is increased by heating the intake raw material as the measure to increase the temperature in the reaction chamber. Description will be made below on a means to heat the injected raw material using exhaust heat and un-reacted composition of the system.

The reference character 99 is a low temperature heat transfer unit of a heat exchanger which heats the raw material to be injected to the reformer engine 92 using exhaust heat from the fuel battery 93. Since temperature of the exhaust heat of the fuel battery is lower than temperature of the exhaust heat of the reformer engine of the internal combustion engine, the word "low" is attached to the low temperature heat transfer unit. The reference character 100 is a heat-amount control valve, and the amount of heat supplied to the raw material from the low

temperature heat transfer unit 99 can be controlled by adjusting the heat-amount control valve 100. The low temperature heat transfer unit 99 in the figure has a pipe through which a heat transfer medium flows, but the intake pipe of the reformer engine 92 may be constructed so as to be arranged in the outer wall surface of the fuel battery 93. This structure has an advantage in that the heat transfer medium of the low temperature heat transfer unit 99 can be eliminated.

The reference character 101 is a high temperature heat transfer unit of a heat exchanger which heats the raw material to be injected to the reformer engine 92 using the exhaust heat from the reformer engine 92. The reference character 102 is a heat-amount control valve, and the amount of heat supplied to the raw material from the high temperature heat transfer unit 101 can be controlled by adjusting the heat-amount control valve 102. Similarly to the low temperature heat transfer unit 99, the heat transfer medium of the high temperature heat transfer unit 101 may be eliminated by arranging the intake pipe of the reformer engine 92 in the outer wall surface of the reformer engine 92.

The reference character 103 is a heater which heats the raw material to be injected to the reformer engine 92 using the un-reacted raw material classified by the fuel

selecting means 94 as the fuel. The heater 103 is composed of a burner and a heat transfer unit. The reference character 104 is a supplied amount control valve for the un-reacted raw material, and in the heater 103, the flame temperature of the burner is brought close to a target value by controlling the supplied amount control valve 104 to control the amount of supplying the un-reacted raw material. The reference character 105 is also a supplied amount control valve for the un-reacted raw material, and the heater uses the un-reacted component of the fuel battery 93 similarly as the heating fuel. Assuming that the raw material is methane and the reaction fuel is hydrogen, the major component of the un-reacted raw material is carbon monoxide and the major component of the un-reacted fuel is hydrogen. Therefore, the heater 103 has an advantage in that the supplying amounts of the un-reacted raw material and the un-reacted fuel having different flame temperatures can be controlled independently from each other, and accordingly the amount of supplied heat can be accurately controlled.

The reference character 106 is a temperature control means which performs temperature control of the various kinds of units in the fuel battery system. The reference character 107 is a reformer engine intake gas temperature measuring means which measures temperature of intake gas of

the reformer engine. The reference character 108 is an internal combustion engine controller which controls a reaction form of each of the reaction chambers of the reformer engine, for example, ignition timing, equivalent ratio, compression ratio and so on. The reference character 109 is an energy control means which generates an operator command and a command signal to each of the components corresponding to vehicle information.

The fuel battery system having the construction of FIG. 1 is characterized as follows. First, exhaust heat of the system can be effectively used. The present system has many heat sources and heating fuels because it has the fuel battery and the internal combustion engine. By using these heat sources and the heating fuel to heat the raw material of the reformer engine 92, an amount of produced hydrogen can be increased. Second, the raw material is gradually heated starting from the heat source having a lower temperature. The relation L1 < L2 < L3 is satisfied where L1 is a length of the intake pipe between the reformer engine 92 and heater 103, L2 is a length of the intake pipe between the reformer engine 92 and the high temperature heat transfer unit 101, and L3 is a length of the intake pipe between the reformer engine and the low temperature heat transfer unit 99. Third, in the present system, the operating temperature control of the fuel battery 93 and

the reformer engine 92 is easy because the heat balance of each of the components is monitored and controlled. Fourth, the output characteristic of the system can be controlled by controlling the reformer engine 92 because the total output of the system can be estimated from the delivery amount of the reaction fuel and the mechanical output of the reformer engine 92. Fifth, the vehicle can be driven as a hybrid vehicle of series type even in the event of failure in the fuel battery because the vehicle mount the energy converting means 94 for converting the mechanical output from the reformer engine 92 to electric energy.

FIG. 2 shows the details of the temperature control means. Referring to the figure, the temperature control means 106 is composed of six control means.

The operating control of the reformer engine is important because the efficiency of the system is determined by the producing amount of hydrogen and the mechanical output of the reformer engine. The producing amount of hydrogen of the reformer engine depends on the temperature of the reaction chamber. In order to increase the temperature in the reaction chamber, it is effective to control the intake gas temperature. Further, because the explosive energy accompanied by the reforming reaction just after the top dead point is want to be used when the mechanical characteristic of the reformer engine is taken

into consideration, it is required to instantaneously induce explosion and instantaneously conclude the reforming reaction by increasing the temperature in the reaction chamber at the top dead point above the self-ignition temperature of the reaction fuel. Further, since the temperature of the fuel to be supplied to the fuel battery is increased as the temperature in the reaction chamber of the reformer engine is increased, the temperature of the fuel battery may exceeds a range of its operating temperature.

The temperature control means will be described below.

The reference character 111 is an internal combustion engine intake air temperature control means which generates an intake gas temperature control command Tint-h* to a high temperature system control means, an intake gas temperature control command Tint-ref* to a heater control means and an operation control command ωe^* to the reformer engine by receiving intake gas temperature information Tint of the reformer engine 92 and reformer operating information of the internal combustion engine controller 108, for example, an equivalent ratio ϕ, a maximum attainable pressure Pmax, a rotating speed Ne. Since the temperature control means is independent from the engine controller, a conventional engine controller can be used for the internal combustion engine controller, and the operation control command ωe^*

does not need to be changed from a conventional engine control command. Further, the cost can be reduced by using the conventional engine controller.

The reference character 112 is a fuel battery operating temperature control means which monitors whether or not the fuel battery is maintained at an appropriate operating temperature and generates an intake gas temperature Tint-1* to a low temperature system control means and an intake gas temperature control command Tint-fc* to a heater control means by receiving operating temperature information of the fuel battery 93, for example, an operating temperature Tfc, an electric generation efficiency ηfc, a humidity in the fuel battery ρfc and so on.

The reference character 113 is the high temperature system control means which receives supplied heat amount information Qh from the high temperature heat transfer unit 101 and the intake gas temperature control command Tint-h* from the internal combustion engine intake gas control means 111, and outputs an operation amount r102 to the heat amount control valve 102.

The reference character 114 is the heater control means which receives the intake gas temperature control command Tint-ref* from the internal combustion engine intake gas temperature control means 111, the intake gas

temperature control command Tint-fc* from the fuel battery operating temperature control means 112 and the heat temperature information Tft from the heater 103, and outputs operating amounts r104 and r105 to the un-reacted raw material supply amount control valve 104 and the un-reacted fuel supply amount control valve 105, respectively.

The reference character 115 is the low temperature system control means which receives supplied heat amount information Ql from the low temperature heat transfer unit 99 and the intake gas temperature control command Tint-l* from the fuel battery operating temperature control means 112, and outputs an operating amount r100 to the heat amount control valve 100.

The reference character 116 is a system cooling-system control means which receives the intake gas temperature information Tint and the operation temperature Tfc and generates a system cooling-system control command Tcl* in the normal state. A conventional cooling unit may be used as the system cooling unit. Further, the system cooling-system control means 116 has a function to shut down heat by operating the control valve when any one of the reformer engine 92, the fuel battery 93 and the intake gas temperatures of the reformer engine 92 is abnormally increased.

The reference character 117 is a temperature

information total control means which compares temperature information of each of the components with commands from the energy control means 109 to output operating commands Rref, Rfc and Rcl to the internal combustion engine intake gas temperature control means 11, the fuel battery operating temperature control means 112 and the system cooling-system control means 116, respectively.

The control means of FIG. 2 operate as follows.

When drive energy of the vehicle is necessary, the energy control means 109 outputs a reaction product increasing command signal to the temperature information total control means 117. The temperature information total control means 117 acquires the operating information and the intake gas temperature information of the reformer engine 92 from the internal combustion engine intake gas temperature control means 111, and sets a target intake gas temperature to increase the amount of the heating fuel or to increase the ratio of the fuel higher in burning temperature supplied to the heater having an excellent temperature response. Then, when the amount of heat exhausted from the reformer engine is stabilized, the temperature control means 106 decreases the amount of fuel supplied to the heater to stabilize the intake gas temperature to the target value.

FIG. 3 shows an embodiment of a vehicle mounting an

energy generating system in accordance with the present invention.

The reference character 121 is a speed control means which mechanically changes speed of the output of mechanical power from the reformer engine 92. The reference character 122 is a drive force control means which controls driving force sharing of the drive force transmitted to the drive shaft 91 between the mechanical driving force from the speed control means 121 and the electric driving force from the motor 98.

As an embodiment of an energy generating system in accordance with the present invention, FIG. 4 shows a case where an energy generating system is an internal combustion engine composed of a plurality of cylinder. The reference characters 11 to 14 are reaction chambers. In regard to the reaction chamber 11, the reference character 15 is a piston, and the reference character 16 is an output shaft, and the reference character 17 is a rod connecting between the output shaft and the piston. The reference character 18 are balance shafts for reducing fluctuation of the pistons individually belonging to the reaction chambers 11 to 14. Similarly, the piston 19 and the rod 20 are provided in the reaction chamber 12, the piston 21 and the rod 22 are provided in the reaction chamber 14, and the piston 23 and the rod 24 are provided in the reaction chamber 14. As an

embodiment, description will be made on a case where the reaction chamber 11 and the reaction chamber 13 perform exothermic reforming reaction, and the reaction chamber 12 and the reaction chamber 14 perform endothermic reforming reaction.

The supplied raw materials are assumed to be methanol and oxygen. In the reaction chambers 11 and 13, heat is generated by the exothermic reaction, and the pistons 15 and 21 are pushed downward by the operating fluid of combustion gas to generate mechanical power in the output shaft 16 through the rods 17 and 22. Further, reaction product composed of major components of un-reacted methanol, hydrogen, steam, carbon monoxide and carbon dioxide is generated. The reaction product generated in the reaction chambers 11 and 13 is supplied to the reaction chambers 12 and 14. The mechanical power generated in the reaction chambers 11 and 13becomes power to pushing upward the pistons 19 and 23through the output shaft 16 to perform compression work in the reaction chambers 12 and 14. In the reaction chambers 12 and 14 receiving the compression work, a high pressure and high temperature state is formed to cause endothermic reforming reaction. For example, the following reaction between the un-reacted methanol and the steam in the reaction product occurs.

$$CH_3OH + H_2O = CO_2 + 3H_2 - 131 \text{ kJ/mole} \quad \ldots(1)$$

The reaction expressed by Formula (1) is called as steam reforming in which 3 moles of hydrogen is produced from 1 mole of methanol. If an amount of un-reacted methanol is small, fuel supply units are provided in the reaction chambers 12 and 14.

Therein, if the mechanical power generated in the reaction chambers 11 and 13 is larger than the compression work in the reaction chambers 12 and 14, mechanical power is output to the outside through the output shaft.

Further, in a case where the energy generating system is mounted on a vehicle, methanol of the fuel can be produced through the following formula using deceleration energy of the vehicle, and the recovered energy can be stored as the fuel. That is,

$$CO + 2H_2 = CH_3OH \qquad \ldots(2)$$

The reformer and internal combustion engine system having the structure shown in FIG. 4 is characterized as follows. That is, in this system, the single internal combustion engine can perform the partial oxidation reaction and the steam reforming reaction or the combined reforming reaction, and can supply heat and hydrogen and power.

As an embodiment of an energy generating system in accordance with the present invention, FIG. 5 shows a case where air is pumped to the fuel battery using exhaust

energy from the internal combustion engine. The reference character 131 is compressor, and the compressor 131 has two turbines , and the two turbines are arranged on a single axis and connected by a mechanical shaft to each other. One of the turbines of the compressor 131 is arranged in the path of the pipe through which the reaction product produced by the reformer engine 92 is supplied to the fuel battery 92, and the other is arranged in the path of the pipe through which air is conveyed to the fuel battery. In the compressor, the turbine in the exhaust gas side is rotated using the exhaust energy of the reformer engine 92, and the turbine in the air side rotated by the reaction force pumps air to the fuel battery.

As an embodiment of an energy generating system in accordance with the present invention, FIG. 6 shows a case where air is pumped to the fuel battery from a cylinder of the internal combustion engine. The reference character 141 is a cylinder composing the reformer engine which is used for pumping air to the fuel battery. The air pumping cylinder 141 sucks only air, and pumps air to the fuel battery using mechanical power generated the other cylinders having reaction chambers performing the reforming reaction.

FIG. 7 shows an example of an energy generating system in accordance with the present invention. The energy

generating system produces a reaction product having higher chemical energy by receiving a raw material and mechanical power. The reference character 31 is the energy generating system in accordance with the present invention, and the reference character 32 is the injected raw material, and the reference character 33 is the input mechanical power, and the reference character 34 is the reaction product produced by the energy generating system. Assuming, as an example, that the raw material 32 is methanol and the reaction product 34 is hydrogen, reaction producing hydrogen from methanol will be described. A high temperature and high pressure atmosphere is formed by adding mechanical power 33 to an atmosphere of methanol and steam to cause the steam reforming reaction producing hydrogen expressed by Formula (1). The reaction of Formula (1) is an endothermic reaction, and is accelerated at a temperature of atmosphere above 500 K. By performing the steam reforming, 3 moles of hydrogen is produced from 1 mole of methanol. The low-level heat value per 1 mole of methanol is 675 kJ/mole, and the low-level heat value per 1 mole of hydrogen is 240 kJ/mole. Therefore, the reaction is equivalent to that the chemical heat energy of 1 mole of methanol is increased from 675 kJ to 720 kJ/mole.

Further, the energy generating system produces the reaction product 34 having a combustion characteristic

different from the raw material 32 by receiving the raw material 32 and the mechanical power 33. As an example, a reaction producing dimethyl ether (hereinafter, referred to as DME) from methanol will be described below. A high temperature and high pressure atmosphere is formed by using methanol as the raw material 32 and adding mechanical power 33 from the outside to cause the following reaction.

$$2CH_3OH = CH_3OCH_3 + H_2O \qquad \ldots(3)$$

DME can be produced by the reaction of Formula (3). Cetane numbers are compared as indexes expressing combustion properties of methanol and DME. The cetane number is an index expressing an ignition property. The cetane number of methanol is 5, and on the other hand the cetane number of DME is 55 to 60. Therefore, using the energy generating system in accordance with the present invention, the raw material of methanol can be reformed to DME of the reaction product having a different combustion property. Therein, the combustion property may be any one of a self-ignition temperature, a flame propagation speed and an octane number.

FIG. 8 shows an example of an energy generating system comprising an energy generator as a front stage reactor for producing a reaction product by receiving a raw material and mechanical power; and a rear stage reactor for generating energy by receiving the reaction product. The

reference character 41 is the front stage reactor, and the reference character 42 is the rear stage reactor. The reference character 43 is the raw material to be injected to the front stage reactor 41, and the reference character 44 is the mechanical power supplied to the front stage reactor 41. Further, the reference character 45 is the reaction product produced by the front stage reactor 41, and the reference character 46 is the energy generated by the rear stage reactor 42. As an example, description will be made on a case where the front stage reactor 41 is a compression engine, and the rear stage reactor 42 is a fuel battery.

The raw materials 43 are assumed to be methanol and steam. The reaction of Formula (1) is caused by injecting the raw materials 43 into a high temperature and high pressure atmosphere in the compression engine formed by the mechanical power from the outside to produce hydrogen as the reaction product 45. Hydrogen of the reaction product 45 is supplied to the fuel battery to generate energy 46.

FIG. 9 shows an example of an energy generating system comprising an energy generator as a front stage reactor for generating mechanical power and producing a reaction product by receiving a raw material; and a rear stage reactor for generating energy by receiving the reaction product. The reference character 51 is the front

stage reactor, and the reference character 52 is the rear stage reactor. The reference character 53 is the raw material to be injected to the front stage reactor 51, and the reference character 54 is an exciting means for supplying a trigger of the reaction to the front stage reactor 51. The reference character 55 is the mechanical power generated by the front stage reactor 51, and the reference character 56 is the reaction product produced by the front stage reactor 51. The reference character 57 is energy generated by the rear stage reactor 52. As an example, description will be made on a case where the front stage reactor 51 is a compression-and-expansion engine, and the rear stage reactor 52 is a fuel battery.

The raw material 53 is assumed to be methanol. When the state in the reaction chamber of the compression-and-expansion engine is made richer than the stoichiometric ratio and added with ignition energy by the exciting means 54, the following partial oxidation reaction is caused.

$$CH_3OH + 1/2O_2 = CO_2 + 2H_2 + 155 \text{ kJ/mole} \quad \ldots(4)$$

Since the reaction of Formula (4) is exothermic, the compression-and-expansion engine can perform expansion work and compression work, and further can generate mechanical power to the outside. Hydrogen produced as the reaction product 56 is supplied to the fuel battery to generate energy 57.

FIG. 10 shows an example of an energy generating system comprising an energy generator as a front stage reactor for producing a reaction product and generating mechanical power by receiving a raw material and mechanical power; and a rear stage reactor for generating energy by receiving the reaction product. The reference character 61 is the front stage reactor, and the reference character 62 is the rear stage reactor. The reference character 63 is the raw material to be injected to the front stage reactor 61, and the reference character 64 is mechanical power supplied to the front stage reactor 61. The reference character 65 is the mechanical power generated by the front stage reactor 61. The reference character 66 is the reaction product produced by the front stage reactor 61. The reference character 67 is energy generated by the rear stage reactor 62. As an example, description will be made on a case where the front stage reactor 61 is a compression-and-expansion engine, and the rear stage reactor 62 is a fuel battery.

The raw materials 63 are assumed to be methanol and oxygen. When the state in the reaction chamber of the compression-and-expansion engine is made richer than the stoichiometric ratio and added with compression work by the mechanical power 64 to form a high pressure and high temperature atmosphere, the reaction of Formula (3) is

caused. Since the reaction of Formula (3) is exothermic, the compression-and-expansion engine can perform expansion work and compression work, and further can generate mechanical power to the outside. Hydrogen produced as the reaction product 66 is supplied to the fuel battery to generate energy 57.

FIG. 11 shows an example of an energy generating system comprising a front stage reactor which has a time period for generating mechanical power, for receiving mechanical power or for receiving mechanical power and at the same time generating mechanical power while producing a reaction product; and a rear stage reactor for generating energy by receiving the reaction product. The reference character 71 is the front stage reactor, and the reference character 72 is the rear stage reactor. The reference character 73 is the raw material to be injected to the front stage reactor 71, and the reference character 74 is mechanical power supplied to the front stage reactor 71. The reference character 75 is the mechanical power generated by the front stage reactor 71, and the reference character 76 is the reaction product produced by the front stage reactor 71. The reference character 77 is a switch for controlling the mechanical power supplied to the front stage reactor 71, and the reference character 78 is a switch for controlling the mechanical power generated by

the front stage reactor 71. The reference character 79 is energy generated by the rear stage reactor 72. As an example, description will be made on a case where the front stage reactor 71 is a compression-and-expansion engine, and the rear stage reactor 72 is a fuel battery.

At cold starting, the temperature of the fuel battery is lower than the operating temperature, and accordingly heating is necessary. Therefore, the compression-and-expansion engine heats the fuel battery using discharging heat by the sacrifice of an amount of producing hydrogen. After the temperature of the fuel battery reaches the operating temperature, the operation is shifted to an operation attaching importance to hydrogen production. In a case where the raw materials 73 are methanol, steam and oxygen, the reaction form in the reaction chamber of the compression-and-expansion engine, the partial oxidation reaction of Formula (1) of exothermic reaction is performed at cold starting, and the steam reforming reaction of Formula (2) is performed after the temperature of the fuel battery reaches the operating temperature. At that time, the switch 77 works to the direction to increase the mechanical power 74 supplied to the front stage reactor 71 is increased, and the switch 78 works to the direction to stop the mechanical power 75 from the front stage reactor 71. During that time period, the rear stage reactor 72

generates energy 79 using the reaction product 76 of hydrogen from the front stage reactor 71.

FIG. 12 shows an example of an energy generating system comprising a front stage reactor having an apparatus for generating mechanical power and producing a reaction product by receiving a raw material; a front stage reactor having an apparatus for producing a reaction product by receiving the reaction product and mechanical power; and a rear stage reactor for generating energy by receiving the reaction product from the front stage reactor. The reference character 81 is the front stage reactor having the apparatus for generating mechanical power and producing a reaction product by receiving a raw material, the reference character 83 is the front stage reactor having the apparatus for producing a reaction product by receiving the reaction product and mechanical power, and the reference character 83 is the rear stage reactor. The reference character 84 is the raw material to be supplied to the front stage reactor 81, and the reference character 85 is an exciting means for supplying a trigger of the reaction to the front stage reactor 81. The reference character 86 is the mechanical power generated by the front stage reactor 81 and to be supplied to the front stage reactor 82, and the reference character 87 is the reaction product produced by the front stage reactor 81 and to be

supplied to the front stage reactor 82, and the reference character 88 is the reaction product generated by the front stage reactor 82. The reference character 89 is energy generated by the rear stage reactor 83. As an example, description will be made on a case where the front stage reactor 81 is a compression-and-expansion engine, and the front stage reactor 82 is a compression engine, and the rear stage reactor 52 is a fuel battery.

The raw materials 84 are assumed to be methanol and oxygen. In the front stage reactor 81, the partial oxidation reaction of Formula (1) is performed to generate the mechanical power 86 and to produce the reaction product 85. The reaction product 85 is composed of major components of un-reacted methanol, hydrogen, steam, carbon monoxide and carbon dioxide. By the mechanical power 86, the reaction product 85 injected into the front stage reactor 82 causes the steam reforming reaction of Formula (2) of the reaction between methanol and steam, or a combined reforming reaction of mixture of Formula (1) and Formula (2). Since there are the reactions of Formula (1) and Formula (2) in this system, both of heat and hydrogen can be stably supplied to the fuel battery.

In the present embodiment, the apparatus for producing a reaction product and generating mechanical power by receiving a raw material and the apparatus for

producing a reaction product by receiving the mechanical power and the mechanical power are used as the front stage reactors. However, there is no problem in that a reactor producing mechanical power and a reaction product by receiving a raw material and mechanical power used for the front stage reactor. Further, the layout of the various kinds of front stage reactors is not limited to the series configuration, and in addition, number of the front stage reactors may be two or more.

The above are embodiments of the present invention, and description has been made on the energy generating system having the front stage reactor(s) and the rear stage reactor, and on the vehicle mounting the energy generating system. Although it has been described that the heating fuel for heating the raw material to be supplied to the front stage reactor is the un-reacted component, the raw material and the reaction product may be used for the heating fuel.

Although the internal combustion engine has been used for the front stage reactor as an example, an external combustion engine may be used for the front stage reactor. Similarly, although the heat sources for heating the raw material through the heat transfer means have been described by taking the reformer engine and the fuel battery, motor driving means such as a motor, an inverter,

a secondary battery and a mechanical load may be used as the heat sources. It is no need to say that if there are any heat sources other than the reformer engine, the fuel battery, the motor, the motor driving means and the mechanical load, heat of the other heat sources may be used. Further, although the fuel battery has been used for the rear stage reactor as an example, a heat engine, a light smiting apparatus or a sound apparatus may be used for the rear stage reactor. Furthermore, there is no need to say that the present invention is applicable to the other means of transportation such as ship, railway vehicle as well as the vehicle, and a chemical plant and an electric power generation facility and so on.

Another embodiment of a construction of a vehicle using the present invention will be described below.

FIG. 13 is an embodiment of a vehicle mounting an energy generating system in accordance with the present invention. The reference character 211 is a drive shaft of the vehicle. The reference character 212 is a reformer engine which characterizes the present invention, and generates hydrogen, heat and mechanical power by partially oxidizing methanol with oxygen in atmosphere. Therein, the reformer engine in this description means a thing capable of generating both of hydrogen and mechanical power by the reforming reaction. The detailed explanation on the

reformer engine 212 is to be described later.

The reference character 213 is a fuel battery which generates direct current electric power by supplying the hydrogen obtained by the reformer engine 212 to the fuel battery electrode. Further, the fuel battery 213 can be speedy brought to an efficiently reactive temperature by receiving the heat generated by the reformer engine 212.

The reference character 214 is an electric generator which converts the mechanical power generated by the reformer engine 212 into electric energy. The reference character 215 is an alternating current electric power converting means which converts the alternating current electric power obtained by the electric generator 214 into direct current electric power. Therein, the alternating current electric power converting means is generally an equivalent to what is called as a converter, and composed of a diode bridge and so on.

The reference character 216 is an electricity storing means for which a secondary battery such as a nickel-hydrogen battery, a lithium battery or the like, or a capacitor bank, an electric double layer capacitor or the like is generally used. The electric power obtained by the fuel battery 213 and the electric generator 214 is stored in the electricity storing means 216.

The reference character 217 is a direct current

electric power converting means which is generally an equivalent to what is called as an inverter. The reference character 218 is the motor, and an alternating current motor such as an induction motor, a synchronous motor, a reluctance motor or the like is generally used for the motor because of toughness and high efficiency. The direct current electric power converting means 217 is provided to drive the alternating current motor 217.

The reference character 219 is an energy control means which generates command signals to individual components corresponding to driver's commands such as an accelerator opening and vehicle information such as a vehicle speed. Since the present system has two parallel means of the fuel battery 213 and the electric generator 214 as the energy sources of the motor 218, the energy control means 219 is provided in order to determine an optimum electric power generating ratio corresponding to the operating state.

The fuel battery system having the construction of FIG. 13 is characterized as follows. First, since the additional electric energy generating means is provided separately from the fuel battery, electric power can be supplied even when the temperature of the fuel battery is low at such as a starting period. Secondly, since the reformer engine 212 has an integrated function of a

reformer for supplying the hydrogen fuel to the fuel battery and an engine for supplying mechanical power to the electric generator, the volume of the system can be made smaller compared to that in a case where a reformer and an engine are separately mounted. Thirdly, by using heat exchange between the reformer 212 and the fuel battery 213, the temperature of the fuel battery 213 can be easily kept at the optimum value and accordingly the fuel battery 213 can be efficiently operated. Fourthly, since electric power can be supplied using the electric generator even in the event of failure of the fuel battery, a tough system can be constructed.

The present system is characterized by the reformer engine 212. The reformer engine 212 will be described below, referring to FIG. 14.

Referring to FIG. 14, the reference character 221 is a reaction chamber, the reference character 222 is a piston, the reference character 223 is a crank, and the reference character 224 is a mechanical output shaft. The reformer engine 212 performs both of reforming reaction and exothermic reaction in the reaction chamber. Therein, the reforming reaction means a reaction producing hydrogen from a raw material of a chemical compound including hydrogen as a composition, and the exothermic reaction means a reaction generating heat at occurring of the reaction. Although

methane, methanol, DME (dimethyl ester) or the like is generally used as the raw material of the reforming reaction, the present invention does not limit a specified fuel. Here, description will be made on the behavior in a case where methanol is used as the raw material.

The piston 222 is reciprocally movably arranged in the cylindrical reaction chamber 221, and the piston 222 is attached to the crank 223 through a connection rod. The reciprocal motion of the piston 222 is converted into rotation motion by the crank 223, and the rotation motion is output by the mechanical output shaft 224.

The reference character 225 is an intake port, the reference character 226 is a fuel injection valve, the reference character 227 is a fuel pipe, the reference character 228 is a sweeping port, and the reference character 229 is a water injection valve. The reference character 230 is an intake valve, the reference character 321 is an exhaust valve, and the reference character 232 is an ignition plug.

The reformer engine 212 sucks atmospheric air through the intake port 225 and compress the atmospheric air in the reaction chamber 221. Methanol is injected through the fuel injection valve 226 at the top dead point of the piston 222, and the mixed gas of the methanol and the sucked atmospheric air is ignited by the ignition plug 232 to be

reacted. Although the embodiment having the ignition plug 232 as the reaction trigger means similarly to the conventional internal combustion engine is shown here, it is possible to use a method of performing the reforming reaction using compression heat instead of igniting by the ignition plug 232 and a method of performing the reforming using a catalyst or a burner. The reaction trigger means is selected by taking the hydrogen production efficiency and easiness of the temperature control method into consideration. Further, two or more kinds of reaction trigger means may be used.

The reaction product is swept out through the sweeping port 228. Since these reaction strokes are equivalent to those of a 4-stroke engine, detailed explanation is omitted here.

The reference character 233 is a reformed gas delivery pipe, the reference character 234 is an exhaust port, and the reference character 235 is a valve mechanism. The valve mechanism 235 changes the flow path of the reaction product swept out through the sweeping port 228 depending on the reaction state of the reaction chamber 221. If the reaction product is a hydrogen-rich reformed gas, the reaction product is delivered to the fuel battery 213 via reformed gas delivery pipe 233 by the valve mechanism 235. If not, the reaction product is delivered to the

outside via an exhaust port 234 by the valve mechanism 235.

The reference character 236 is a heat transfer means, and the reference character 237 is an encoder attached to the electric generator 214. The heat transfer means 236 has functions to transfer heat generated from the reformer engine 212 to the fuel battery 213, or to transfer heat generated from the fuel battery 213 to the reformer engine 212. In some cases, the heat transfer means 236 uses a means called as a heat clutch for changing its thermal resistance if necessary. Further, since the mechanical output shaft 224 of the reformer engine 212 is directly linked to the electric generator 214 in this construction, the encoder 237 used as a speed sensor of the electric generator 214 can also measure the rotating speed of the reformer engine. In the reformer engine shown in FIG. 14, since a rotation speed of the reformer engine is in proportion to an amount of delivered hydrogen, an amount of fuel supplied to the fuel battery can be accurately known by the encoder 237 if a temperature in the reaction chamber 221 is known.

The reference character 240 is a reformer engine control means for controlling the reformer engine 212, the reference character 241 is an injecting amount control means for controlling the amount of methanol fuel injected through the fuel injection valve 226 and the amount of

water injected through the water injection valve 229, the reference character 242 is a valve opening-and-closing control means for controlling opening and closing of the intake valve 230 and the exhaust valve 231, and the reference character 243 is a valve control means for controlling the valve mechanism 235.

Operation of the reformer engine 212 in accordance with the present invention will be described below.

In the reaction chamber 211 of the reformer engine, any one of reactions expressed by the following four thermal formulas occurs.

$CH_3OH + 2O_2 \rightarrow 2H_2O + CO_2 + 727$ kJ/mole ...(5)

$CH_3OH + 1/2O_2 \rightarrow 2H_2 + CO_2 + 155$ kJ/mole ...(6)

$CH_3OH + 1/3O_2 + 1/3\ H_2O \rightarrow CO_2 + 7/3\ H_2 + 59.7$ kJ/mole ..(7)

$CH_3OH + H_2O \rightarrow CO_2 + 3\ H_2 - 131$ kJ/mole ...(8)

Formula (5) is a reaction formula of complete oxidation. Formula (6) is a reaction called as partial reforming, and Formula (7) is a reaction called as combined reforming, and Formula (8) is a reaction called as steam reforming. The water injection valve 229 in FIG. 14 is provided in order to obtain the reactions of Formula (7) and Formula (8).

When the above formulas are arranged in decreasing order of amount of produced hydrogen per 1 mole of methanol,

the following order is obtained.

Formula (8) > Formula (7) > Formula (6) > Formula (5)

Therein, hydrogen is not produced by the reaction of Formula (5).

When the above formulas are arranged in decreasing order of amount of generated heat, the following order is obtained.

Formula (5) > Formula (6) > Formula (7) > Formula (8)

Therein, since Formula (8) is endothermic reaction, the reaction is unsuitable to extract mechanical power to the outside.

It can be understood from the above results that in order to increase the ratio of electric power generated by the electric generator 214, the reactions expressed by the Formula (5) and Formula (6) are performed in the reaction chamber 221, and that in order to mainly use the fuel battery 213, the reaction expressed by Formula (7) is performed. Further, when temperature of the fuel battery 213 is high, the reaction expressed by Formula (8) is performed to cool by the endothermic reaction. When the reactions expressed by Formula (6), (7) or (8) is performed, the valve control means 243 operates the valve mechanism 235 to connect the sweeping port 228 to the reformed gas delivery pipe 233. Thereby, the produced hydrogen is delivered to the fuel battery 213. Furthermore, when the

reaction expressed by Formula (5) is performed, the sweeping port 234 is connected to the exhaust port 234 to discharge the reaction product to the outside. These operations will be described below in detail.

When temperature of the fuel battery is considerably lower than the optimum temperature at such as a starting period, methanol in the reformer engine 212 is perfectly oxidized as shown by Formula (5) to extract the total energy of methanol in the form of heat. In this case, the total energy is output from the mechanical output shaft 224 to be stored in the electricity storing means 216 through the electric generator 214. By doing so, the present system can extract energy through the electric generator even in the event that the fuel battery can not be used. The operation of the reformer engine 212 at that time is equivalent to a methanol engine. The exhaust heat generated from the reformer engine is conveyed to the fuel battery 213 by the heat transfer means 236 to worm up the fuel battery 213. By doing so, there is an effect that the start-up time of the fuel battery 213 can be shortened.

When the temperature of the fuel battery is increased and the fuel battery becomes capable of generating electricity, the partial oxidation reaction of Formula (6) is performed in the reformer engine. Since this reaction is an exothermic reaction, mechanical power can be extracted

while hydrogen is being produced. The exhaust heat of this reaction is used to preheat the gas to the fuel battery 213 using the heat transfer means 236. Formula (6) indicates that 3 moles of the reaction product can be obtained from 1.5 moles of the material to be reacted. Therefore, in order to accelerate the hydrogen producing reaction, it is preferable that the compression ratio is set to a lower value compared to that in the case of the reaction of Formula (1). The intake valve 230 and the exhaust valve 231 in FIG. 14 are individually controlled by the valve opening-and-closing control means 242 to cope with change of the compression ratio.

When the fuel battery becomes at the optimum temperature and the remaining electricity in the electricity storing means 216 is not so much, the reformer engine 212 performs the combined reforming shown by Formula (7). Although the amount of heat generated by this reaction is small, it is possible to extract an amount of mechanical power enough to pump up the produced hydrogen to be delivered.

When the reaction chamber 221 becomes at the sufficiently high temperature, the steam reforming of Formula (8) is performed. Since the reaction of Formula (8) is an endothermic reaction, the piston 222 can not directly moved reciprocally, and accordingly the reformed gas can

not be delivered to the fuel battery 213. Therefore, the electric generator 214 is used as a motor to pump up the reformed gas to be delivered to the fuel battery. The alternating current power converting means 215 converts the direct current power obtained from the electricity storing means 216 to alternating current power to rotate the electric generator 214. Although the energy necessary for the electric generator 214 is required as the driving torque at an initial compression period, the loss as a whole becomes as very small as the pumping loss if the moment of inertia of the mechanical output shaft 224 is large. Further, since the steam reforming reaction of Formula (8) is the highest in the hydrogen production efficiency among the presented four reactions, highly efficient operation can be performed even deducing the loss due to moving of the electric generator. The reaction chamber 221 at a high temperature is cooled by performing the steam reforming to prevent the temperature of the reaction chamber 221 from raising to an excessively high temperature.

Although description has been made on the method of decreasing the temperature of the reaction chamber 221, a method of increasing the temperature of the reaction chamber 221 is also necessary because the reforming temperature is different depending on the type of the

reaction. As the method of increasing the temperature of the reaction chamber, there are a method that a heat source is attached to the cylinder, a method that the exothermic reaction of Formula (5) is once and transiently caused. Further, the above methods can be performed together with the method that the compression ratio is temporarily increased by operating the opening and closing timing of the intake valve 230 and the exhaust valve 231. This method has an advantage in that temperature can be instantaneously increased by adiabatic compression.

By employing the construction of FIG. 14 as the reformer engine, the following advantages can be attained.

Firstly, the structure can make the whole system small in size and light in weight. This construction has the both functions of internal combustion engine and reformer, and accordingly the reformer engine can be operated as an internal combustion engine to secure the electric power generation even when the fuel battery is in a low performance state. In order to provide such functions described above, it has been necessary to mount both of a reformer and an engine, which causes a problem of making the total system large. Further, since the amount of the hydrogen fuel is controlled by the rotation speed of the reformer engine in this construction, a sufficient amount of hydrogen fuel can be supplied by operating the reformer

engine at a high speed though the reformer engine has a small displacement volume. This also contributes to make the total system smaller.

Secondary, this construction has an advantage in that the reaction efficiency is high. This is because control of the ratio of reaction products can be easy performed, and accordingly an exhausted amount of un-reacted object is small. Since the reaction in this construction occurs within a closed space, the volume of the reaction chamber is known. Further, the pressure before reaction can be detected by the controlling of opening and closing timing of the intake valve 230. Therefore, the number of moles of the reaction product can be accurately controlled by actually measuring or estimating from the cooling water temperature the temperature just before fuel injection by the fuel injection valve 232. An amount of the reaction product can be also easily known, and accordingly there is an advantage in that the amount of electric generation of the fuel battery can be accurately estimated.

Thirdly, there is an advantage in that the reformer engine can easily cope with a rapid load fluctuation. Since the produced hydrogen fuel in this construction is always pumped and supplied to the fuel battery by the reformer engine, the amount of hydrogen fuel can be instantaneously controlled.

Although the construction of the basic portions of the reformer engine 212 has been described above, additional parts can be attached to the reformer engine in order to improve the reforming efficiency. For example, it is effective that a CO selective oxidation device is inserted into the path of the reformed gas delivery pipe 233 to change CO affecting an ill effect on the reaction to harmless CO_2. Further, it is also effective to insert an H_2 selection permeable membrane. Since these additional parts are known in the art, detailed description is omitted here.

FIG. 15 shows an embodiment of a mechanism for collecting water injected from the water injection valve 229. Therein, the reference character 251 is a cooler, the reference character 252 is water tank, and the reference character 253 is a water pump.

From Formula (5), H_2O and CO_2 are produced. By cooling down these to room temperature by the cooler 251, the H_2O can be collected as a liquid. The collected H_2O is temporarily stored in the water tank 252 and then delivered to the water injection valve 229 by the water pump 253.

Although the operation of the reformer engine 212 has been described, it is to be understood that the reformer engine 212 may be changed to the other various embodiments without departing from the scope of the present invention. For example, although FIG. 14 has shown the construction

using the 4-strok internal combustion engine, the reforming reaction can be performed in the reaction chamber of a 2-strok internal combustion engine. Further, it is obvious that instead of the internal combustion engine, employing of an external combustion engine using the exothermic reactions of Formulas (5) to (7) does not depart from the scope of the present invention.

Description will be made below on the energy control means 219 for controlling a vehicle mounting the present fuel battery system, particularly on the method of controlling the reformer engine, referring to FIG. 16.

FIG. 16 shows an embodiment of the energy control means 219 shown in FIG. 13.

A required electric power Preq required to be generated by the present fuel battery system can be expressed by the sum of a driving electric power Pdrv directly used for driving the vehicle and a required charge electric power Pchg used for an amount of increasing stored electricity in the electricity storing means 16. The driving electric power can be calculated by an output converting means 261 which receives an accelerator opening degree θac and a vehicle speed Vvh. In general, the output converting means 261 has a torque map for converting the accelerator opening degree to a vehicle requiring torque, and calculates the driving electric power as the product of

the torque obtained from the torque map and the vehicle speed. The required charging electric power Pchg is determined from a remaining capacity in electricity storing means SOC using a required generating electric power map 262.

The required electric power Preq is converted to a rotation speed base command $\omega 1$ by a rotation speed setting means 263 and a limiter 264. Therein, the rotation speed setting means uses a temperature Tcyl in the reaction chamber 221 and employed reaction formula information Nr as the inputs. The employed reaction formula information Nr specifies a reaction formula to be performed in the reaction chamber 221. In a case of using Formula (5), for example, integer 1 is transmitted to the rotation speed setting means 263. The method of determining the employed reaction formula information is to be described later. The limiter is determined by an electric generator maximum rotation speed, a charge state of the electricity storing means 16, a maximum electric generation amount of the fuel battery and so on.

Operation of the rotation speed setting means 263 will be briefly described.

The reformer engine 212 converts the chemical energy of the methanol fuel to the chemical energy of hydrogen to be supplied to the fuel battery and to the mechanical

energy by mechanically pressing down of the piston 222. Since the chemical energy of hydrogen produced per 1 cycle of the reformer engine 212 is in proportion to molar number of produced hydrogen, the amount of the chemical energy of converted hydrogen per unit time can be expressed by the following equation in a simplified form.

$$Pi(H2) = Kci \cdot Pri \cdot Vri \cdot \omega e/Tcyl \qquad \ldots(9)$$

Therein, the suffix i specifies a used reaction formula, and, for example, is 1 when Formula (5) is used. Setting i = {1, 2, 3, 4} because the reaction formulas considering at present are Formulas (5) to (8). Pi(H2) is chemical energy of hydrogen when the reaction formula i is used, Kci is a constant, Pri is a pressure of the reaction chamber 221 at a time just before reaction when the reaction formula i is used, Vri is a volume of the reaction chamber 221 at a time just before reaction when the reaction formula i is used, ωe is a rotation speed of the reformer engine 212, and Tcyl is a measured value or an estimated value of temperature of the reaction chamber. Since Ki, Pri and Vri are determined if the reaction formula i is determined, the chemical energy of hydrogen Pi(H2) when the reaction formula i is used can be expressed as Equation (10).

$$Pi(H2) = Kci' \cdot \omega e/Tcyl \qquad \ldots(10)$$

where Kci' is a constant.

On the other hand, the mechanical energy produced per 1 cycle of the reformer engine 212 can be expressed by the integration of the product of pressure and volume with time. Although the pressure generally changes with time, the amount of the mechanical energy per unit time can be approximately expressed as follows.

$$Pi(Mech) = Kmi \cdot Pmi \cdot \omega e \qquad \ldots(11)$$

where Kmi is a constant.

It can be understood from Equations (9) and (11) that there is the following relation between the reformer engine rotation speed ωe and the required electric power Preq.

$$\begin{aligned} Preq &= \eta fc \cdot Pi(H2) + \eta e \cdot Pi(Mech) \\ &= (\eta fc \cdot Kci'/Tcyl + \eta e \cdot Kmi \cdot Pmi)\, \omega e \\ &= (A/Tcyl + B)\, \omega e \qquad \ldots(12) \end{aligned}$$

where ηfc is an efficiency of the fuel battery, ηe is an engine efficiency of the reformer engine, A and B are constants determined by the reaction formula. A rotation speed command (here, ωe) can be easily determined from the required electric power Preq using Equation (12). Further, although the efficiencies are assumed to be constant in the above equation for purpose of simplification, in general the efficiencies η are functions of reaction chamber temperature Tcyl and rotation speed ωe. Taking these into consideration, the required

amount of electric generation power Preq is a function of rotation speed ωe and reaction chamber temperature Tcyl. Therefore, the rotation speed ωe can be determined using a means such as a map.

In FIG. 16, a final rotation speed command ω* of the reformer engine is determined by adding a rotation speed correction value $\Delta\omega$ to a rotation speed base command ω1. This is provided in order that a measured generated electric power Pgen is made to approach close to a requested electric power Preq by correcting the rotation speed when there is any difference between the requested electric power Preq and the measured generated electric power Pgen. The operation of the rotation speed correcting means is to be described later.

The rotation speed command ω* of the reformer engine finally obtained is transmitted to a controller of the electric generator 214. The electric generator 214 performs speed control. And the rotation speed of the electric generator 214 follows the rotation speed command ω* of the reformer engine. Since the electric generator 214 is attached to the mechanical output shaft 224 of the reformer engine, the rotation speed of the reformer engine can be controlled by the speed control of the electric generator 214.

The method of determining the employed reaction

formula information Nr will be described below.

Al though the reformer engine 212 can generate energy by selecting the various kinds of reactions, it is preferable to select a reaction among them which makes the total energy generation efficiency maximum. In order to do so, there is provided a means for estimating the total efficiency when each of the reaction formulas is used. Therein, the reference character 266 is a rotation speed converting means for converting a real rotation speed of the electric generator to a real rotation speed of the reformer engine. In general, since the mechanical output shaft 224 of the reformer engine 212 is connected to the rotation shaft of the electric generator 214 by a gear or pulley, the rotation speed converting means 266 is necessary in order to take the rotation speed ratio of the mechanical output shaft 224 of the reformer engine 212 to the rotation shaft of the electric generator 214 into consideration.

The reference character 267 is a total efficiency estimating means when each of the formulas is used. The reference character 268 is a reaction formula efficiency comparing means which compares efficiencies at using the individual formulas obtained from the means 267, and selects a reaction formula among them by which the efficiency becomes maximum, and then outputs the employed

reaction formula information Nr. The employed reaction formula information Nr is output to the reformer engine control means 240 which controls the compression ratio, the fuel injection amount, the water injection amount, the valve position and so on.

The reference character 269 is a torque converting means which generates a torque command to the motor 218 from the accelerator opening degree θac.

FIG. 17 is a block diagram explaining the rotation speed correcting means 265.

In general, an electric power can be expressed by the product of a rotation speed and a torque. In the rotation speed correcting means 265, the correction value of the rotation speed is calculated by dividing an electric power error of the electric generator by a real torque of the electric generator. The electric power error ΔPg of the electric generator is calculated by proportionally distributing the total electric power error ΔP. Therein, the ratio of an amount of electric generation of the fuel battery to the total amount of electric power generation is defined as an electric power distribution ratio, and is denoted by α . For example, assuming the fuel battery efficiency to be 0.5 and the engine efficiency to be 0.3 when the system is operated according to Formula (2), the electric distribution ratio α is calculated as follows.

Initially, since the chemical energy of 1 mole of hydrogen is 286 kJ/mole, the chemical energy of the produced hydrogen is 572 kJ/mole per 1 mole of methanol. By multiplying the fuel battery efficiency to the value, the output of the fuel battery is calculated to be 286 kJ/mole per 1 mole of methanol.

On the other hand, since the reaction heat is 155 kJ/mole and the engine efficiency is 0.3, the mechanical energy becomes 46.5 kJ/mole per 1 mole of methanol. Therefore, the electric power distribution ratio becomes as follows.

$$\alpha = 286/(286 + 46.5) = 0.860 \qquad \ldots(13)$$

The above calculation is executed in an electric power distribution ratio calculating means 271. Although the calculation here is executed by simplifying the efficiencies as constants, the calculation accuracy can be improved by taking the rotation speed information and the reaction chamber temperature into consideration.

The reference character 272 is an electric generator power error calculating means which calculates an electric generator power error by multiplying $(1-\alpha)$ to the electric power error. The calculated electric generator power error is divided by the real torque of the electric generator to be output as the rotation speed correction value $\Delta\omega$ through a low-pass filter 274. The real torque of the

electric generator may be actually measured using a torque sensor, but the real torque of the electric generator here is estimated from a real rotation speed ω real of the reformer engine and the electric generator generating power Pg.

Since the electric power can be expressed by the product of the rotation speed and the torque as described above, the estimated real torque value of the electric generator is an electric generator supplying power divided by the real rotation speed of the electric generator. The electric generator supplying power Pgs can be obtained by correcting the electric generator generating power Pg with respect to the efficiency, and the efficiency can be obtained by inputting the real rotation speed of the electric generator and the generating power Pg of the electric generator to perform map search. The reference character 276 is an efficiency inverse map by which an efficiency is obtained from a rotation speed and a generating electric power. The reference character 277 is an electric generator supply power calculating means, and the reference character 278 is an electric generator real torque value calculating means.

Although the description above has been made on the method of operating the reformer engine 212 by selecting the four reaction formulas shown by Formulas (5) to (8), it

is possible to easily perform a method of continuously operating from Formula (6) to Formula (8).

For example, letting a reaction ratio of Formula (6) be γ, the following formula can be obtained by combining Formula (6) and Formula (8).

$$CH3OH + (\gamma/2)O2 + (1-\gamma)H2O$$

$$\rightarrow (3-\gamma)H2 + CO2 + (286\gamma -131)\ kJ/mole \quad ...(14)$$

In the reformer engine 212 in the present construction, the amount of intake air is determined by the opening and the closing timings of the intake and the exhaust valves and the cylinder volume, the temperature in the reaction chamber. Therefore, the oxygen amount can be estimated by multiplying the oxygen concentration of atmospheric air to the amount of intake air. Further, the amounts of methanol and water can be controlled by controlling the injection amounts of the fuel injection valve and the water injection valve, respectively. As described above, the amount of reaction product can be accurately controlled. Therefore, the reaction expressed by Formula (14) can be easily performed.

Since by using Formula (14) it is possible to perform operation at the completely thermally balanced point (γ = 0.458), the inside of the reaction chamber can be easily maintained at the optimum temperature for reforming.

Although the description above has been made on the

vehicle mounting the fuel battery having the construction that both of the electric power generated by the fuel battery 213 and the mechanical power of the reformer engine 212 are stored in the electricity storing means 216, it is possible to form a vehicle having the construction that the mechanical power generated by the reformer engine 212 is directly transmitted to the wheel shaft 211. In this case, it is necessary to provide a speed control means to the reformer engine 212, but the system can be made small because the electric generator 214 can be eliminated. FIG. 18 shows an embodiment of this construction. In the block diagram, the reference character 280 is a torque composition means. The torque composition means is provided so that the wheel shaft may be directly driven by both of the reformer engine 212 and the motor 218, and can be easily formed by using various kinds of gears. A more simple structure can be obtained by that the rotation shaft of the reformer engine 212 and the rotation shaft of the motor 218 are coaxially arranged, and are touched to and detached from each other using a clutch.

INDUSTRIAL APPLICABILITY

In an energy generating system comprising a reformer engine which is formed by integrating a reformer and a heat engine in a unit and a fuel battery, the present invention

intends to improve the efficiency of the total system by effectively using heat from the fuel battery, the reformer engine and un-reacted fuel to increase inlet temperature of the reformer engine and accordingly to improve the reforming efficiency.